

## Summary

The ANWB, a professional association which enables high level technical assistance on passenger vehicles nationwide, is experiencing an increasing number of battery related failures. Their future goal is to predict an upcoming battery failure and to create the opportunity to respond to the problem in advance. This thesis examines a method capable of determining the battery's state of health and indicating upcoming battery failure. Non-invasive measuring methods are investigated to make the method implementable in practical solutions.

The working principle of batteries applied in the automotive sector will be investigated first to obtain an understanding of the technology which is involved in battery design. Battery technology comprises a combination of chemistry, material, mechanical and electrical science. An aggregation of these technologies yields to a small electrical-energy producing device, referred to as a battery. In the automotive sector lead acid batteries are used in cranking applications

The state of health (SOH) of lead acid batteries is decreasing with age revealing a reduced battery performance. The performance of lead acid batteries is expressed in capacity and peak power delivery. To estimate the battery's SOH the effective performance has to be determined.

The effective performance and therefore the SOH of the battery is gradually decreasing until a cranking failure manifests itself. Batteries can have different failure modes caused by a combination of underlying failure mechanisms. A battery is a closed system and progressing failure mechanisms cannot be observed without the use of invasive methods i.e. to really reveal the battery's SOH the casing has to be opened enabling the internals to be examined which will destroy the battery. Most failures are caused by a combination of different failure mechanisms. Using a non-invasive SOH estimator groups all progressing failure mechanisms together, but enables the SOH to be estimated without destroying the battery. Non-invasive SOH estimators are based on the effective capacity and internal resistance of the battery.

The main task of a battery is to power a cranking system which is cranking a reciprocating combustion engine. The combustion engine produces a variable load on the cranking system which will be observable in the voltage values of the cranking system. Capturing the discharge voltage of the battery while cranking reveals a distinctive shape from which general points occurring in every CVT can be derived. These general points represent features contained by the discharge voltage. In this study the discharge voltage signal is referred to as the "cranking voltage trace" (CVT). The shape of the CVT changes with the battery age and a decreasing SOH. It is expected that features extracted from the CVT change along with the CVT shape. A method is proposed to discover a relation between the change in features and battery SOH.

The proposed SOH monitoring method involves non-invasive measuring of the CVT utilizing a standardized connection implemented in all European vehicles since 2002. To capture the cranking voltage trace measuring equipment is prototyped which is able to sample an analog voltage signal at the required frequency and resolution. A successful prototype proved the feasibility of measuring the CVT with simple hardware as the ANWB is intending.

CVT data of batteries with a decreasing SOH is required to research the existence of a relation between features extracted from the CVT and battery SOH. A test setup has been created to generate CVT data. The test setup is used to produce CVT data by cranking two combustion engines

of different fuel type while capturing the CVT. Five test batteries will be used to crank the engines of the test setup. Three of the five test batteries will be subjected to an accelerated aging process, which ages the batteries in weeks instead of years. For this purpose an accelerated battery aging device was constructed which successfully aged the batteries in a relatively short period. At certain intervals during the aging period the test setup was used to generate CVT data which resulted in approximately 200 CVT's usable for analysis.

Before the CVT data can be analysed it has to be processed first. The data is made identifiable by use of a personal table of labels for each test battery and a CVT identification number. Using these identifiers generated CVT data can be linked to that particular battery and cranking event. A Matlab script imports the CVT data and performs a selection of the peaks and valleys contained by the CVT signal shape. All features of the CVT data are based on these peaks and valleys. After the peak and valley selection has finished the Matlab script will start with the extraction of features. 27 features are extracted from the CVT data and stored in a table of features containing an unique set of features in each row of the table. Once the table of features is filled with features originating from the cranking events executed by the test setup, a data analysis can be performed.

A data analysis is performed to research the existence of a relation between features extracted from the CVT and the battery SOH. The features are classified according to the battery SOH and put through different types of analysis. In the process of analysis, the unusable features are discarded resulting in a select set of features which is most capable of revealing a relation to battery SOH. Two features survived the process of data analysis and are selected to be implemented in the proposed SOH monitoring method. As expected, it is discovered that these features are temperature dependent.

The proposed method SOH monitoring method is a continuous method and therefore needs a reference value to map the change in battery SOH over time. To make the feature values of different battery engine combinations comparable they are normalized by scaling them to a personal baseline. A personal baseline belongs to a particular battery engine combination and uses the feature values captured on first use of the battery. Scaling all succeeding feature values to the baseline values creates normalized values capable of revealing a change relative to the baseline. Since the baseline belongs to new batteries, the change will indicate that batteries are getting older and their SOH is changing. The normalized values are still able to reveal a relation to battery SOH and produce an upcoming failure warning. Three failure warning methods are tested from which two predicted an upcoming failure of one of the test batteries with 100% accuracy.